Atomic Standard of Pressure

NIST scientists are working with other National Measurement Institutes to develop a high-accuracy primary standard for pressure in the range 0.3 MPa to 7 MPa based on fundamental physical properties of helium. With this new standard, it will be possible to test models of piston-cylinder sets and to reduce the uncertainty in the assignment of their effective area. This work is expected to enable new innovations in the manufacturing sector.

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NIST will determine the pressure $p(\varepsilon,T)$ of helium gas by measuring and calculating the dielectric constant, $\varepsilon(p,T)$. Ultimately, the uncertainties from the theory, impurities, and the electrical and temperature measurements are expected to be smaller than those of existing pressure standards (piston gages). When this occurs, the dielectric constant of helium will become the basis for a new pressure standard. The standard will be disseminated by calibrating piston-cylinder sets and by using the helium standard to measure $\varepsilon(p,T)$ of argon. Argon is chosen because it is readily available in high purity and because its dielectric polarizability is eight times larger than that of helium.

NIST, along with other NMIs are developing a new device to measure pressure. This program will help revolutionize the realization of pressure standards and enable better calibration of piston-cylinder sets, and new innovations in the manufacturing sector.

Below 300 kPa, the primary pressure standard at NIST is a 3-meter mercury manometer. Above 300 kPa, the pressure standards are commercially manufactured piston-cylinder sets. These sets are complicated artifacts. In operation, the cylinder and piston deform significantly and the piston rotates continuously to insure gas lubrication. Because of these complications, piston-cylinder sets are calibrated using the primary-standard mercury manometer below 300 kPa and their performance is extrapolated to higher pressures using numerical models of the coupled gas flow and elastic distortions. The extrapolation cannot be checked with existing technologies; thus, it is not fully trusted. Furthermore, piston-cylinder sets exhibit poorly understood specie and gas flow dependencies. When $\varepsilon(p,T)$ of helium becomes the pressure standard, it will be possible to test models of piston-cylinder sets and to reduce the uncertainty in the assignment of their effective area.

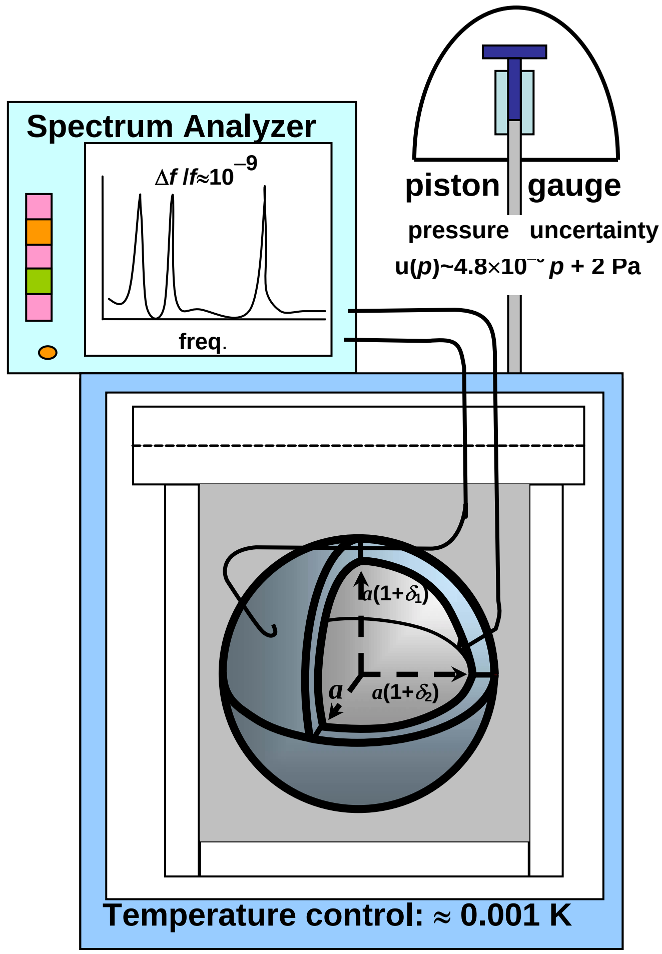
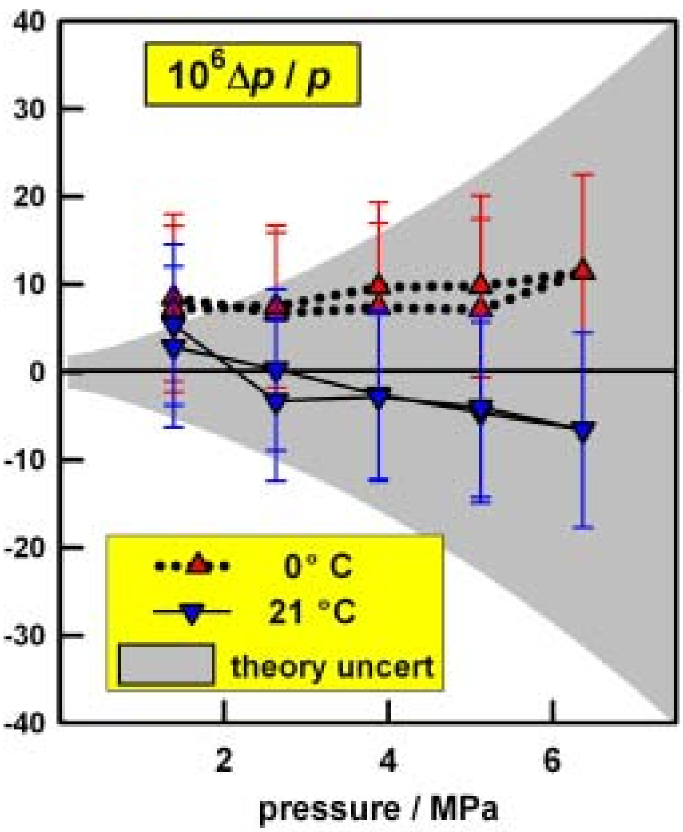


Figure 1. ***The dielectric permittivity of helium or argon is measured using an quasi-spherical cavity resonator. Each of the selected electromagnetic modes (TM_{11}, TE_{11}, TM_{12}, TE_{12}) are split into 3 sharp resonances. The ratio of the resonance frequency divided by the vacuum frequency of the modes is used to measure the dielectric permittivity of the gas inside the resonator.***

Fractional difference between the pressure determined from the microwave resonance frequencies of a helium-filled cavity and the pressure determined by NIST's standards. The cavity was operated at 0 °C and 21 °C. During the next few months, we expect that the theoretical and experimental uncertainties will be reduced by a factor of two.

Progress: Figure 1 sketches the apparatus that we use to measure $\varepsilon(p,T)$, the dielectric permittivities of helium and argon, in the ranges 0.1 to 7 MPa and 0 to 50°C. We determine $\varepsilon(p,T)$ from measurements of the temperature, pressure, and microwave resonance frequencies of a gas-filled quasi-spherical cavity. The cavity's shape differs from that of a perfect sphere by only a few parts in one thousand. This small distortion is just enough to lift the triple degeneracy of the selected microwave resonance frequencies, thereby facilitating frequency measurements with part-per-billion uncertainties.

***Figure 2** shows the measurements of $\varepsilon(p,21\ °C)$ and $\varepsilon(p,0\ °C)$ of helium and the deviations of the measured values from the theoretical values.*



The values measured as the pressure increased and as the pressure decreased for four microwave triplets spanning the frequency range 2.7 GHz to 7.6 GHz are mutually consistent, within the thicknesses of the lines on ***Figure 2.***

The helium-filled microwave cavity is bounded by walls made of copper-plated maraging steel. The theory must account for the shrinkage of these walls (and the cavity) under applied pressure. We calculated the shrinkage from the isothermal compressibility κ_T of maraging steel samples cut from the same billet as the walls. We determined κ_T of maraging steel with an uncertainty of 0.1 % by measuring the frequencies of the mechanical resonances of the cylindrical samples. This is an advance in the state-of-the art of resonance ultrasonic spectroscopy. During the next few months, we will reduce the uncertainties of the pressure and temperature measurements. Our colleagues are also reducing the uncertainty of the theoretical calculations of $\varepsilon(p,T)$. Thus, we expect the uncertainty of the new standard to be reduced.

Impacts: (1) This program will revolutionize the realization of pressure standards. (2) In earlier work, we invented the gas-filled, quasi-spherical cavities to simplify acoustic thermometry.

Now, NIST and other NMIs are using these cavities to determine the imperfections of the internationally accepted temperature scale, ITS–90.